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RESEARCH DEPARTMENT

A BAND II RECEIVING AERIAL FOR A MOTOR CAR

Report No. G-077

(1960/16)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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1. INTRODUCTION

Although the very-high-frequency (v.h.f.) sound service in Band II (87·5 – 95 Mc/s) now provides virtually complete coverage of the United Kingdom, the car receivers in use in this country rarely incorporate a v.h.f. range. This is probably because the medium-frequency (m.f.) transmitters give reasonably satisfactory reception in a car of all British programmes. The main drawbacks are fading, man-made interference, and (at night) interference from continental stations; but these are less important when listening in a car, since a lower grade of service is tolerated compared with, for instance, listening in the home.

In Germany only a few m.f. channels are available for use and the service is consequently poor compared with that on v.h.f. Correspondingly, about twenty types of German-made car-radio receivers incorporating a v.h.f. band are available. Several German manufacturers are also marketing all-transistor battery a.m./f.m. receivers suitable for use in a car. A similar trend might be expected in those countries where the m.f. service, although more satisfactory, still leaves much to be desired; there are, however, serious technical difficulties in achieving satisfactory v.h.f. reception in a moving vehicle. Because of the physical limitations imposed on the design, the sensitivity of the aerial is low and may vary considerably with the orientation of the car. On the other hand, the susceptibility to interference from the ignition systems of near-by cars is much greater than in the case of home listening. There is, therefore, a need for an aerial which is sensitive to the wanted signal (whatever the direction of arrival) and relatively insensitive to interference from near-by cars, while at the same time having a neat appearance. In this report, a horizontal V aerial is described which goes some way towards meeting these requirements. A photograph of the aerial mounted on a car is shown in Fig. 1.

If the v.h.f. transmissions were vertically polarized, a whip aerial on the roof would be the best solution. A vertical aerial can also be used for horizontally-polarized transmissions, but this means that its sensitivity depends on the distortion of the incident field caused by the car. One possible position is on the wing, but the horizontal radiation pattern (h.r.p.) is then likely to be far from uniform. A horizontal aerial as high as practicable above the roof of the car seems likely to be most sensitive to the wanted signal, whilst at the same time discriminating to some extent against very near sources such as other cars.

2. THEORETICAL DESIGN CONSIDERATIONS

2.1. Horizontal Radiation Pattern

One simple type of horizontally-polarized aerial which has a substantially uniform h.r.p. has been described by Wells;[1] it consists of two 0·5λ elements at right angles in the form of a V, fed from a balanced source. For Band II the dimensions of such an aerial are impracticably large, but by making the elements 0·25λ long

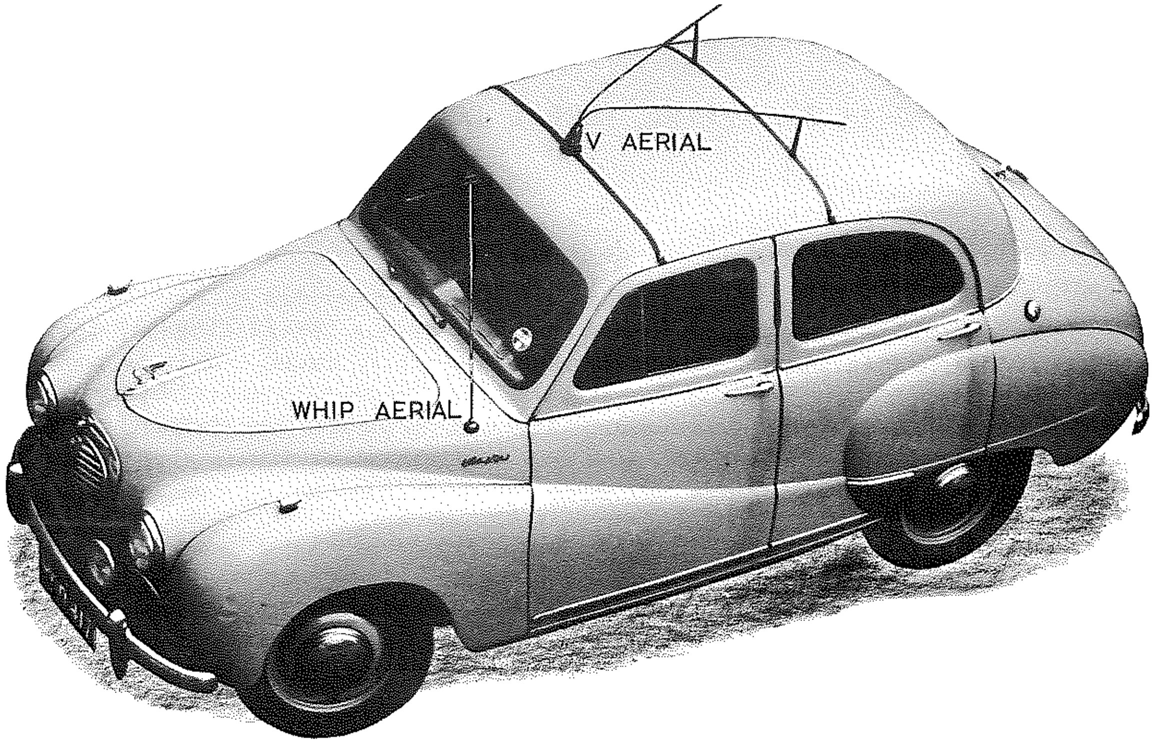

Fig. 1 - V and whip aerials

Wells showed that the h.r.p. is still reasonably uniform. Fig. 2 shows the theoretical radiation patterns in free space for three values of the included angle, assuming the same current in the 0·25 λ elements for all three cases.* The uniformity of the pattern improves as the angle of the V is reduced, but the distant field set up by a given aerial current falls, as do, therefore, the radiation resistance and the bandwidth. The 60° V was chosen as the best compromise between pattern uniformity and radiation resistance. To improve the matching to the receiver, and consequently the sensitivity, the elements were made 0·28 λ long instead of 0·25 λ (see Section 2.2). The h.r.p. for this case, scaled for the same maximum current, is shown by the dotted curve in Fig. 2. Compared with the shorter elements the radiation resistance is increased; in addition, the h.r.p. is more uniform, the ratio of maximum to minimum being 5 dB.

2.2. Aerial Sensitivity

The sensitivity of the car V aerial is conveniently calculated by comparing it with a reference aerial at the same height above ground level; for the time being we will regard both aerials as transmitting.

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*Here we regard the aerial as transmitting; it follows from the reciprocity theorem that the characteristics for reception are precisely the same.

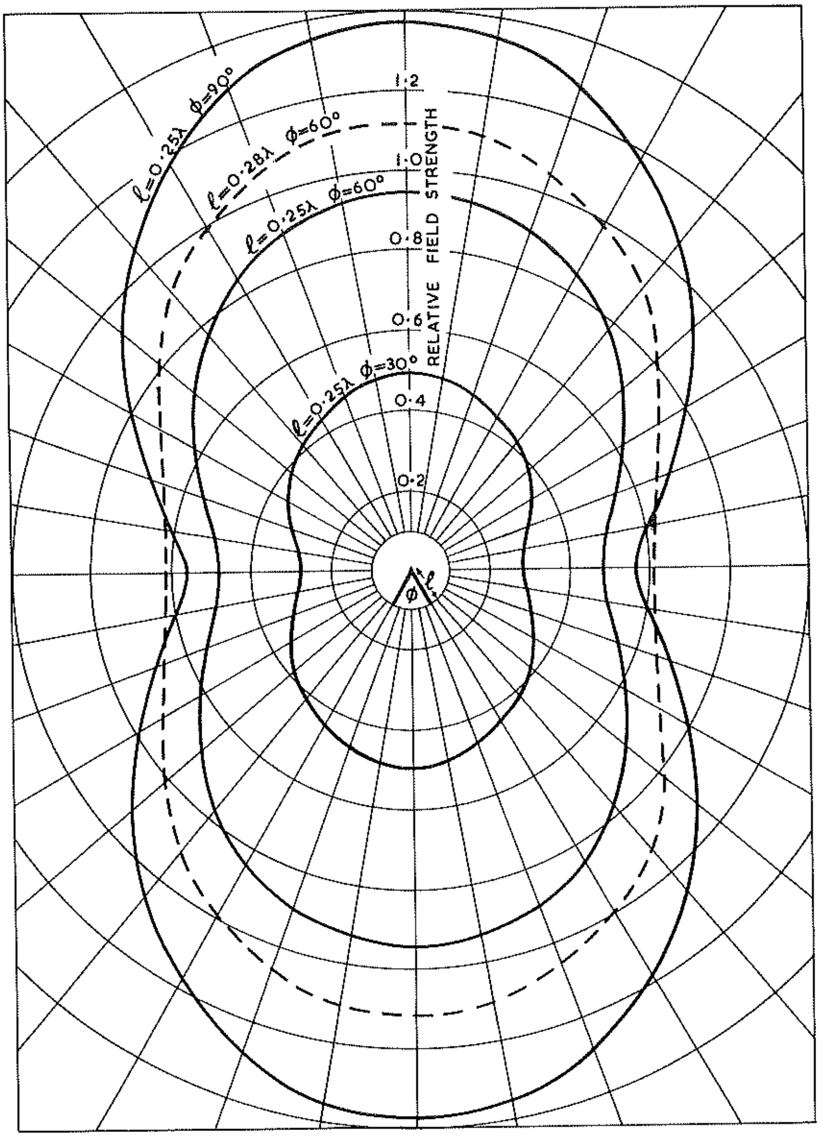

Fig. 2 - Theoretical horizontal radiation pattern of V aerial

The curves are scaled for the same maximum current
in the elements, when transmitting

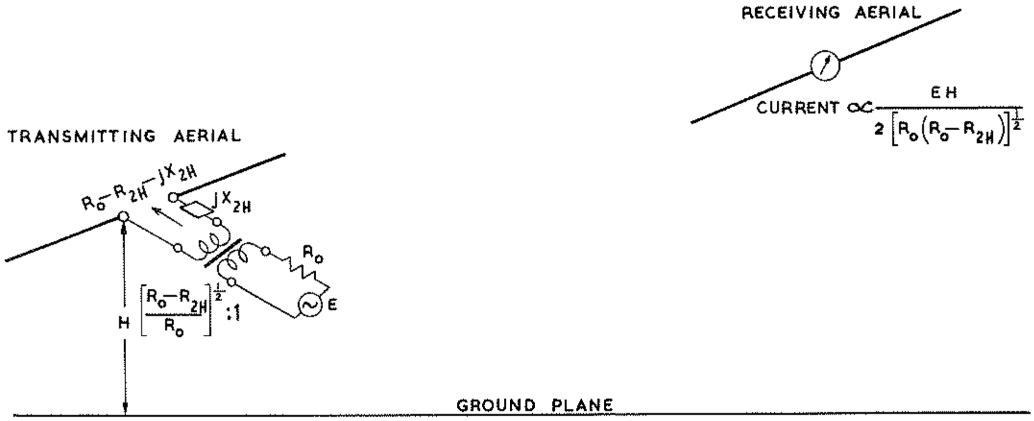
RECEIVING AERIAL
CURRENT $\propto \frac{EH}{2\left[R_o(R_o-R_{2H})\right]^{\frac{1}{2}}}$
TRANSMITTING AERIAL
$R_o-R_{2H}-jX_{2H}$
jX_{2H}
R_o
E
H
$\left[\frac{R_o-R_{2H}}{R_o}\right]^{\frac{1}{2}}:1$
GROUND PLANE

Fig. 3 - Calculation of sensitivity

We will take the reference aerial (Fig. 3) to be a horizontal series-tuned $0{\cdot}5\lambda$ dipole, the impedance in free space being a pure resistance, R_o; taking the ground plane as perfectly conducting, it is equivalent in its effect to an image aerial carrying a current equal and opposite to that of the actual aerial. The input impedance of the reference dipole, height H, is therefore $R_o - R_{2H} - jX_{2H}$, where $R_{2H} + jX_{2H}$ is the mutual impedance between two $0{\cdot}5\lambda$ dipoles spaced $2H$ apart. The reference dipole may be matched to a generator of internal resistance R_o by adding a series reactance $+jX_{2H}$ and coupling through an ideal transformer of turns ratio $\{(R_o - R_{2H})/R_o\}^{½}$. The current induced in a distant parallel receiving aerial, in the direction of maximum radiation, is proportional to the product of the current flowing in the reference dipole and its height above ground level, i.e. to $EH/2\{R_o(R_o - R_{2H})\}^{½}$; this result is, of course, independent of the means by which matching is achieved.

Consider now the same aerial at a height h above the roof of the car; since h is only a few inches, in the first place we will regard the roof as of infinite extent and also as flat and perfectly conducting. The current induced in the distant receiving aerial is the same as for the reference dipole, but with h replacing H and R_{2h}, (the mutual resistance between two $0{\cdot}5\lambda$ dipoles spaced $2h$ apart), replacing R_{2H}.

The ratio of the currents induced by the car aerial and the reference dipole is therefore

$$\frac{h}{H}\left\{\frac{R_o - R_{2H}}{R_o - R_{2h}}\right\}^{½}$$

When $h \ll \lambda$ it may be shown that $(R_o - R_{2h}) \approx 32R_o(h/\lambda)^2$; the current ratio then becomes

$$0{\cdot}18\,\frac{\lambda}{H}\left(1 - \frac{R_{2H}}{R_o}\right)^{½}$$

and is independent of h. Since H is at least $0{\cdot}5\lambda$ we can neglect R_{2H}/R_o* compared with unity, and write the current ratio as approximately

*In the case of the reference dipole, since the height is at least $0{\cdot}5\lambda$ the assumption that the ground is perfectly conducting is immaterial as far as the impedance is concerned; the assumption is also justified in calculating the field at the distant receiving aerial for waves at grazing incidence.

$$0{\cdot}18\frac{\lambda}{H}$$

The ratio of the field due to the V aerial to that of a $0{\cdot}5\lambda$ horizontal dipole, both mounted at the same height above the roof and radiating the same power, has been calculated by an integration based on the theoretical radiation patterns of the two aerials. The mean ratio (i.e. the square root of the ratio of the mean power radiated by the V in all horizontal directions to that radiated by the $0{\cdot}5\lambda$ dipole in a horizontal direction at right angles to the dipole) is 0·71. Using this result, we can compare the car V aerial with the original $0{\cdot}5\lambda$ reference dipole, height H; we obtain for the ratio of the currents induced in the distant receiving aerial

$$0{\cdot}13\frac{\lambda}{H}$$

From the reciprocity theorem it follows that the square of this ratio is the mean (in all horizontal directions) of the power gain of the car V aerial relative to the $0{\cdot}5\lambda$ reference dipole, when both are energized by a distant transmitting aerial. In our case, H = 5 ft 9 in. (1·75 m) and λ = 3·33 m (a frequency of 90 Mc/s); the power gain is therefore 0·062 or −12 dB.

It is important to emphasize at this point that we have assumed that the V aerial is matched, and it is only in this case that the sensitivity is independent of h. As h is reduced the radiation resistance falls rapidly, and even if the aerial were matched at the mid-band frequency it would not remain matched over a band. A height of 6 in. (15 cm) above the roof was chosen as a compromise between sensitivity over the working band and neatness of appearance. To achieve maximum sensitivity the elements were made $0{\cdot}28\lambda$ long (rather than $0{\cdot}25\lambda$) and the aerial was parallel-tuned with a capacitance of 30 $\mu\mu F$.

We must next consider the effect on the calculation of regarding the car roof as infinite in extent. It is again convenient to regard the aerial as transmitting, and mounted on a "hill" (the car body), the "ground" falling away in all directions. As far as the important low-angle radiation is concerned, the effective height of the aerial is therefore greater than the height above the roof, and the sensitivity is consequently greater than that calculated. However, the complicated shape of the car makes it difficult to calculate the magnitude of the increase.

2.3. Equivalent Circuit

The apex of the V was swept down to the car roof as shown in Fig. 1, and there connected by a coaxial lead to the receiver; the parallel tuning capacitor was added at the junction of the aerial and the coaxial lead. This method of connection for a nominally balanced aerial is not technically elegant, but it has the merit of simplicity and also permits the same aerial to be used on m.f.; in practice it gave good results (see Section 3).

The equivalent circuit of the aerial can be derived as illustrated in Fig. 4. The region inside the car is assumed to be screened; the aerial (regarded as transmitting) is then equivalent to one with a generator E connected in series between one branch of the V and the car body. By the process demonstrated in Fig. 4 the aerial current can be regarded as the sum of two components. One component corresponds to the aerial energized in a balanced manner from a generator of voltage E, and the other to an aerial (comprising the two branches of the V commoned at the apex in series with the car body) energized in an unbalanced manner from a generator of voltage E/2. Since the balanced aerial is resonant on v.h.f., the associated

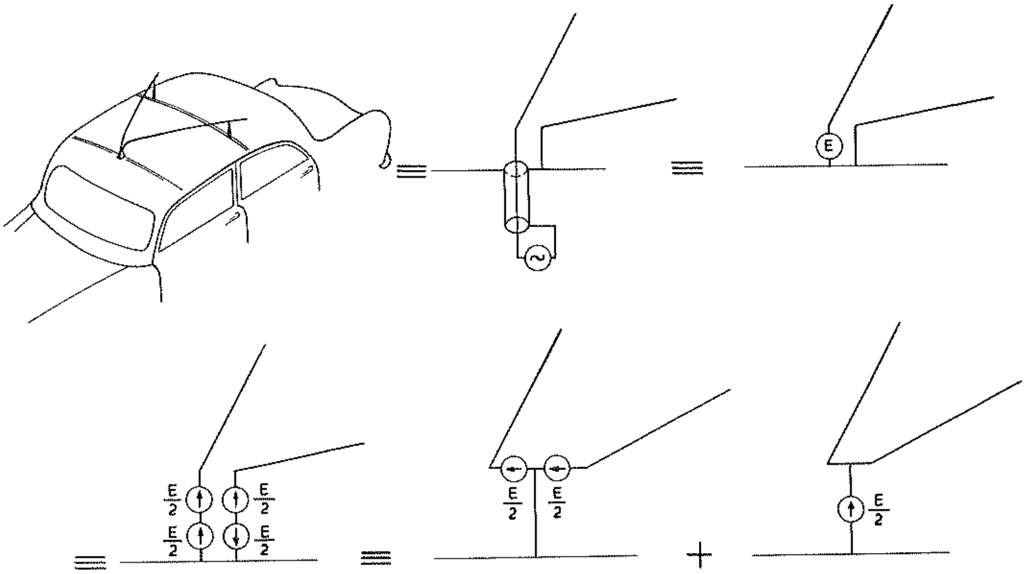

Fig. 4 - Equivalent circuit of V aerial

currents will predominate, and the unbalanced component will not affect the performance to an important extent.

As far as the m.f. band is concerned, due to the small electrical spacing between the two branches of the V, the radiation from the balanced method of excitation will be negligible, and that from the unbalanced excitation will predominate. The aerial will, therefore, radiate mainly vertically-polarized waves, associated with the currents flowing in the short vertical portion above the roof and the vertical component in the car body.

3. MEASURED PERFORMANCE

3.1. V.H.F. Band

The radiation pattern was measured by rotating the vehicle on a large turntable, and measuring the signal induced by two Band II transmissions from a distant station; the test frequencies were 89·1 Mc/s and 93·5 Mc/s. The signal induced in the whip aerial was also measured for comparison purposes; this was mounted on one of the wings and can be seen in Fig. 1.

The measured h.r.p.s are shown in Fig. 5, (a) and (b). For the V aerial the ratio of maximum to minimum is about 5 dB on both frequencies. The close agreement with the theoretical ratio for a 60° V is fortuitous, as the shapes of the predicted and measured patterns are very different. The asymmetry with respect to the axis of the V can arise only from the unbalanced method of feeding, or from local reflections; although the measuring site was relatively unobstructed over a range of about 150 ft (46 m) in all directions, the spatial variations in field strength at the height of the car were about ±2 dB, so that errors of this magnitude are possible.

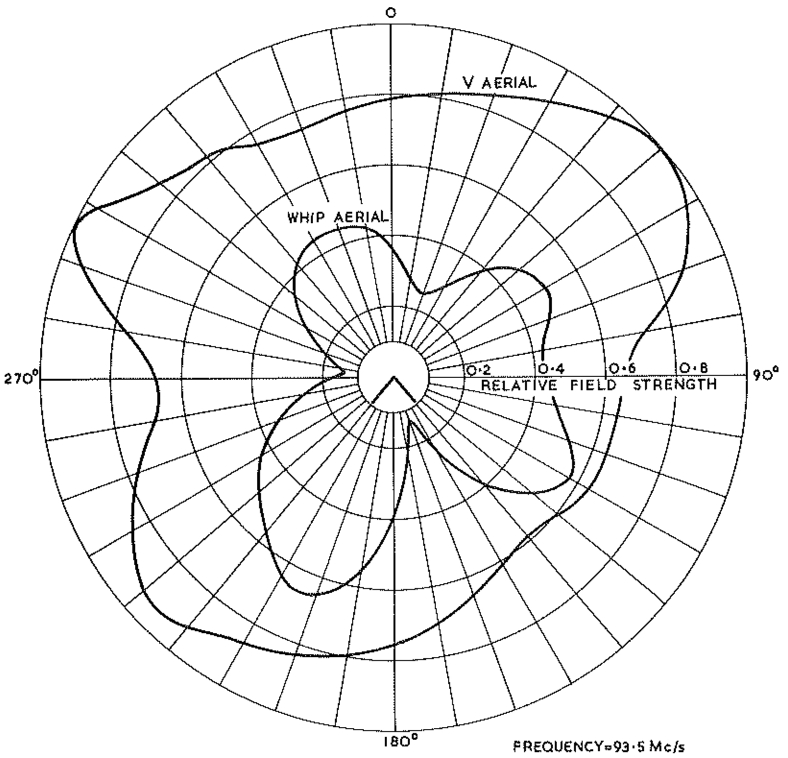

Fig. 5(a) - Measured horizontal radiation patterns of V and whip aerials

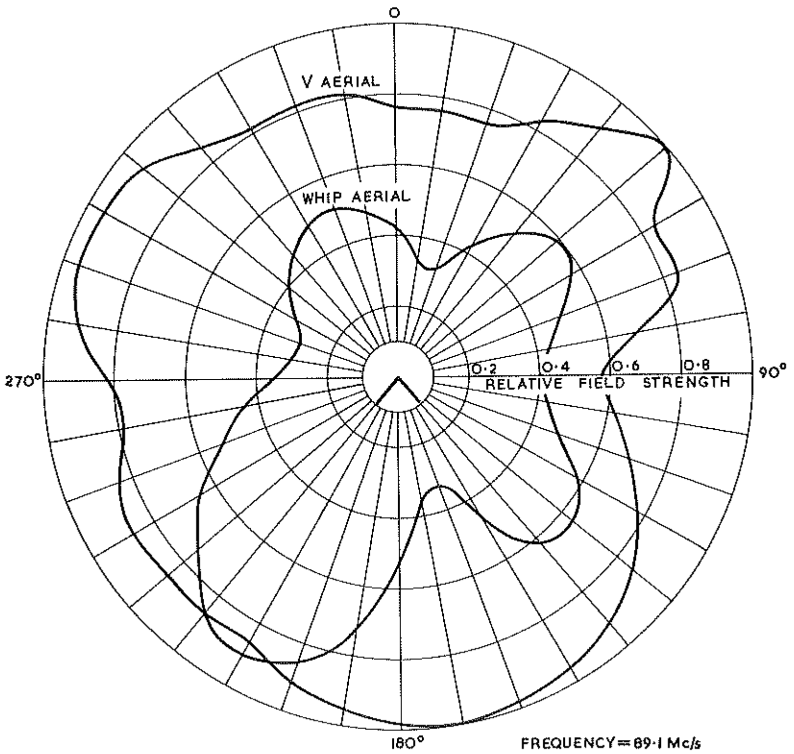

Fig. 5(b) - Measured horizontal radiation patterns of V and whip aerials

The sensitivity was measured with the car off the turntable; the axis of the V was aligned with the direction of the distant transmitting station and the signal induced compared with that for the reference 0·5 λ horizontal dipole. The measurement was repeated at a number of points in order to eliminate the effect of local reflections. To standardize the test conditions, the measurements were made with a 70-ohm attenuator of at least 10 dB interposed between the aerial and the receiver. The effect of mismatch at the receiver input was thus substantially the same for the V and 0·5 λ aerials; ideally, of course, both aerials should be tuned to give the best match to the receiver in the absence of the intervening attenuator.

The results will be expressed in terms of the mean (in all horizontal directions) of the power available from the V, i.e. a circle having the same area as the h.r.p. in Fig. 5. On both test frequencies the mean power available was found to be -13 dB relative to that from the reference 0·5 λ dipole. Bearing in mind that in deriving the theoretical result in Section 2.2 it was assumed that the V aerial was matched to the load (a condition which cannot be achieved over a band of frequencies since the radiation resistance is very low) the measured sensitivity is surprisingly high. One possible explanation is mentioned in Section 2.2, namely that the shape of the car makes the effective height of the aerial appreciably greater than the height above the roof.

The length of the comparison whip aerial was made 2 ft 9 in. (0·84 m) because this gave the maximum induced signal. The radiation patterns were of the same general shape on both frequencies, but the minima were much deeper on one frequency than on the other, the higher ratio of the maximum to minimum values being 15 dB. The mean sensitivity relative to the V was -4 dB on one test frequency and -6 dB on the other test frequency. The performance of the whip was equal to that of the V only over one small arc on one of the two test frequencies; more important, there are deep minima in the h.r.p. of the whip aerial.

3.2. M.F. Band

No precise measurements of the performance of the V aerial on m.f. were made, but it was compared with the whip aerial and the length of the latter was adjusted to give approximately the same signal-to-noise ratio when receiving a distant station. The whip aerial was found to be equivalent when about 2 ft (0·61 m) long; the sensitivity of the V is therefore much less than that of a typical m.f. whip aerial. However, adequate pick-up was obtained in the nominal fringe of a m.f. service area where the field strength was approximately 3 mV/m.

3.3. General Comments on V.H.F. Reception in a Car

In order to avoid excessive interference from the car's own electrical system, adequate suppression is essential. The remedies described below were found necessary on the two cars on which the experiments were carried out, and are considered typical of the minimum general requirements. A suppressor resistor was required at each sparking plug, in addition to that at the distributor already fitted by the manufacturer. Two 1 μF capacitors were also used; one was connected between the primary of the ignition coil and the car body, and the other between the dynamo output terminal and the car body, (the latter capacitor was necessary mainly to reduce interference with m.f. reception). With this arrangement, interference was virtually inaudible when the ambient field at 30 ft (9·1 m) above ground level was about 0·5 mV/m.*

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*Electrical equipment such as windscreen wipers may cause interference at considerably higher signal levels, unless adequately suppressed.

Practical experience of reception conditions has been obtained by fitting two cars with V aerials, and carrying out listening tests in a wide variety of localities over a period of many months. Generally speaking, reception is found to be satisfactory provided the field strength at 30 ft (9·1 m) above ground level is at least 1 mV/m. The grade of service is then limited either by "drop-outs" of the signal (resulting in a sudden increase in the noise level) or by ignition interference if the traffic is dense. In one of the cars tested "drop-outs" are more noticeable than ignition interference, whereas in the other car the reverse is the case, the difference appearing to be associated with the different characteristics of the receivers in the two vehicles.

4. REFERENCE

1. Wells, N., "The Quadrant Aerial: An Omnidirectional Wideband Horizontal Aerial for Short Waves", J.I.E.E., Vol. 91, Part III, December 1944.

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